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# Comparison Of Aerodynamic Characteristics Of Live And Inert 70-mm T231 Gun-Boosted Rockets (U)



EUGENE D. BOYER



DEPARTMENT OF THE ARMY PROJECT No. 5B03-03-001
ORDNANCE RESEARCH AND DEVELOPMENT PROJECT No. TB3-0108

BALLISTIC RESEARCH LABORATORIES

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# COMPARISON OF AERODYNAMIC CHARACTERISTICS OF LIVE AND INERT 70-MM T231 GUN-BOOSTED ROCKETS (U)

Eugene D. Boyer



Department of the Army Project No. 5B03-03-001
Ordnance Research and Development Project No. TB3-0108

A B E R D E E N   P R O V I N G   G R O U N D,   M A R Y L A N D

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BALLISTIC RESEARCH LABORATORIES

MEMORANDUM REPORT NO. 1086

EDBoyer/jcw
Aberdeen Proving Ground, Md.
July 1957

# COMPARISON OF AERODYNAMIC CHARACTERISTICS OF LIVE AND INERT 70-MM T231 GUN-BOOSTED ROCKETS (U)

## ABSTRACT

Firings were made in the Transonic Range of the Ballistic Research Laboratories, to determine the effects of a burning motor on the aerodynamic properties of the 70-mm T231 rocket. A comparison of the aerodynamic properties, with and without a live motor, showed only minor differences. The largest difference is a 10% increase in the normal force which may only be a reflection of the uncertainties of the inertial properties.

TABLE OF SYMBOLS

| | |
|---|---|
| $A$ | Axial moment of inertia |
| $B$ | transverse moment of inertia |
| $d$ | diameter |
| cm | center of mass |
| $K_D$ | drag force coefficient |
| $K_M$ | overturning moment coefficient |
| $K_N$ | normal force coefficient |
| $K_T$ | Magnus moment coefficient |
| $K_H$ | moment coefficient due to cross angular velocity |
| $K_{MA}$ | moment coefficient due to cross acceleration |
| $M$ | Mach number |
| $CP_N$ | center of pressure of the normal force |
| $\phi'_{1,2}$ | turning rates of the epicyclic arms |
| $K_{10}$ | magnitude of nutational arm at mid range |
| $K_{20}$ | magnitude of precessional arm at mid range |
| $\overline{\delta^2}$ | mean yaw squared |
| $\delta_e^2$ | $K_{10}^2 + K_{20}^2 + \dfrac{K_{10}^2\ \phi'_1 - K_{20}^2\ \phi'_2}{\phi'_1 - 0'_2}$ |
| $\lambda_{1,2}$ | yaw damping rates |
| $s$ | gyroscopic stability factor |
| $\overline{s}$ | dynamic stability factor |
| $N$ | number of yaw observations |
| $N_T$ | number of timing observations |
| $\epsilon_Y$ | error in yaw fit |
| $\epsilon_S$ | error in swerve fit |
| $S_L$ | radius of swerving motion |

## INTRODUCTION

With the development of new instrumentation and data analysis techniques it has become possible to employ the spark photography ranges in studying the flight of gun-boosted burning rockets[1,2]. At the request of the Computing Laboratory the 70-mm T231 rocket was tested in the Transonic Range of the Exterior Ballistics Laboratory, in order to determine the effect of the burning motor on the aerodynamic properties of this projectile. A photograph of the projectile is shown in Figure 1. A shadowgraph of the rocket in flight, at 1565 fps, is shown in Figure 2.

The program consisted of the firings of six rounds with burnt motors and eight rounds with live motors. All rounds were fired from a 70-mm open breech launcher (Fig. 3) with a twist of 1/12. The first two rockets fired exhibited very little yaw. Since a minimum of two to three degrees of yaw is desirable in the analysis of the yawing motion it became necessary to induce yaw. This was done by installing a blast deflector (Fig. 4) at the muzzle of the gun for the remainder of the rounds. This device distorts the flow of the gun gases over the model just after ejection and gives the model a tipping tendency.

The rockets were observed for a distance of 680 feet. Reference 3 shows that peak acceleration occurs at about 1300 feet and that zero acceleration occurs at about 2600 feet, the latter part being usually terminal burn out. The acceleration falls very rapidly from the peak to a low level and it seems reasonable to presume that effective burn out occurs nearer 1300 feet than 2600 feet. If a constant rate of change of mass is to be presumed, then it is more realistic to assign a value of burn out at or near 1300 feet, although the exact position is somewhat arbitrary. In the analysis presented here the physical properties of the rocket were assumed to vary linearly between the gun and 1300 feet, 1300 feet being considered complete burn out. The physical properties of the rocket are given in Figure 5.

If the burn out distance had been assumed to be 2600 feet (indicated burn out) the following changes would occur in the data:

| | Inertial properties | Aerodynamic properties | |
|---|---|---|---|
| Mass | + 4% | $K_D$ | + 4% |
| cm | .05 Cal toward base | $K_M$ | + 3% |
| A | + 4% | $K_N$ | + 4% |
| B | + 3% | $CP_N$ | .04 cal toward base |
| | | $K_T$ | + 4% |
| | | $K_H$-$K_{MA}$ | + 3% |

However, it is believed that the 1300 foot "burn out" value is more realistic. At such time when better estimates of the inertial properties are made the coefficients can be recomputed and better values obtained.

A burning rocket generally introduces certain modifications in the data reduction process. For the present case, a rather low thrust rocket with a high burnt weight, the following considerations appear to be sufficient to treat the problem:

1. The acceleration is approximately constant throughout the range of observation, thereby permitting a constant pseudo drag value to be used to process the yaw and swerve to a reasonable degree of accuracy.

2. Since only one third of the total weight is expanded in flight, although the exact variation is not known, it seems possible to estimate the variation of the total mass and radii of gyration to within 10% of a given point.

3. The jet damping appears to be no more than 10% of the aerodynamic damping and can therefore be neglected in the first approximation.

## EXPERIMENTAL RESULTS

### Velocity and Acceleration

The time of flight of each round was measured at twelve points along the first 700 feet of trajectory. These data were numerically differentiated to obtain the velocity and the acceleration along the observed portion of the trajectory. The velocities of the burning rounds are given in Figure 6 as a function of distance along the trajectory. The acceleration appears to be nearly constant. Although the muzzle velocities of five rounds agree to 1% variations of 10% in muzzle velocity are indicated. Drag values for the burnt rounds are given in Table I as pseudo-drag values for the burning rounds are given in Table II. These, of course, reflect the rocket thrust as well.

The burnt rounds were fired at the maximum allowable pressure but the midrange velocities were considerably lower than those of the burning rounds. In an attempt to increase the velocity level the inert filler was removed from the heads of some of the burnt rounds (Fig. 5). The reduction in weight gave higher velocities but still about 10% lower than the burning rockets.

### Overturning Moment

The overturning moment coefficient, $K_M$, for both the burnt and burning rounds is seen in Figure 7 as a function of Mach number. This value has been computed for a center of mass position 3.495 calibers from the base of the model. Assuming a variation of $K_M$ with Mach number similar to that of the seven caliber spinner rocket of Reference 4 there is little if any effect of the burning motor on $K_M$.

### Normal Force and Center of Pressure

The normal force coefficient, $K_N$, and the center of pressure, $CP_N$, are given in Figures 8 and 9. The real, or apparent, 10% rise in $K_N$ for the burning rockets coupled with the apparent lack of variation of $K_M$ is reflected in a rearward shift of the center of pressure of the burning rounds by 0.2 calibers. Since the lift is determined from the swerving

motion of the shell, the change in $K_N$ may be due to erroneous average values for the mass of the shell in flight. An accurate determination of this quantity might lead to better agreement.

Magnus and Damping Moment

The Magnus moment coefficient, $K_T$, and the damping moment coefficient $K_H - K_{MA}$, are plotted in Figures 10 and 11 as a function of Mach number. The scatter of the data in these graphs appears to be associated with non-linear variation of the parameters to some degree - as well as with possible uncertainties of the physical parameters. Treating the burnt rockets alone by the method described in Reference 5 - a strong correlation with effective yaw was obtained (Figs. 12 and 13). Reference 5 shows that the range determined values of damping coefficients are the combinations given below when the force system is nonlinear:

$$(K_H - K_{MA})_{range} = K_{HO} + K_{MAO} + K^*_{H_{\delta}2} \frac{(\phi'_1 K_{20}^2 - \phi'_2 K_{10}^2)}{\phi'_1 - \phi'_2}$$

$$- K^*_{T_{\delta}2} \left(\frac{B}{A}\right)\left(\frac{\phi'_1 + \phi'_2}{\phi'_1 - \phi'_2}\right) (K_{10}^2 - K_{20}^2)$$

and,

$$K_{T_{range}} = K_{T_0} + K^*_{T_{\delta}2} \; \delta_e^2 + K^*_{H_{\delta}2} \left(\frac{A}{B}\right) \left(\frac{K_{10} \phi_1'^2 - K_{20}^2 \phi_2'^2}{\phi'_1 - \phi'_2}\right)$$

where

$$K^*_{H_{\delta}2} = K_{H_{\delta}2} - K_{MA_{\delta}2} + \frac{1}{2} K_{MAO}$$

$$K^*_{T_{\delta}2} = K_{T_{\delta}2} - \frac{1}{2} \; K_{T_0} \; .$$

For the burnt rocket, it is assumed that the value of $K^*_{H_{\delta}2}$ is negligible (there is insufficient data to do otherwise) and the $K_T$ and $K_H - K_{MA}$ data fitted to determine values of $K^*_{T_{\delta}2}$, one obtains values of $-41 \pm 3$ and $-30 \pm 4$ respectively which are in fair agreement for the limited amount of data.

The variation of $K_T$ and $K_H - K_{MA}$ with yaw for the burning projectiles are too uncertain (due to physical parameters) to warrant any attempt to correlate with the effective yaw parameters. In comparson with data of Reference 4 there is about a 20% scatter about the spinner rocket data and there is no clear effect of the burning motor on $K_T$ and $K_H - K_{MA}$.

SUMMARY

A comparison of the aerodynamic properties of the T321 rocket both with and without a live motor showed only minor differences, about a 10% increase in $K_N$ being the largest. These differences may reflect only the uncertainties of the physical characteristics of the burning rocket since these are utilized to infer the aerodynamic properties from the observed motion.

Eugene D. Boyer

EUGENE D. BOYER

APPENDIX A

Table I

AERODYNAMIC DATA BURNT MOTORS

| Rd. | M | $K_D$ | $\overline{\delta^2} \times 10^2$ (Rad.) | $\delta_e^2 \times 10^2$ (Rad.) | $K_M$ | $K_N$ | $K_H$ | $K_T$ | $\lambda_1 \times 10^3$ ($ft^{-1}$) | $\lambda_2 \times 10^3$ ($ft^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|---|
| 3907* | .971 | .1687 | .539 | .537 | 1.85 | .98 | 6.0 | .12 | 1.92 | - .23 |
| 3904 | 1.043 | .1999 | .256 | .254 | 1.76 | .94 | 9.8 | .07 | 2.18 | - .14 |
| 3908* | 1.189 | .1982 | .372 | .456 | 2.00 | .95 | 8.7 | -.01 | 1.71 | .43 |
| 3909* | 1.191 | .2004 | .623 | 1.084 | 1.91 | 1.00 | 12.6 | -.26 | .99 | 1.79 |
| 3906* | 1.193 | .1996 | .471 | .660 | 1.96 | .95 | 10.3 | -.06 | 1.76 | .70 |
| 3910* | 1.206 | .2002 | .640 | 1.087 | 1.89 | .99 | 13.4 | -.26 | 1.11 | 1.78 |

| Rd. | M | s | $\overline{s}$ | N | $N_T$ | $\epsilon y$ (ft.) | $\epsilon s$ (ft.) | $s_L$ (ft.) | $K_{10}$ (Rad.) | $K_{20}$ (Rad.) |
|---|---|---|---|---|---|---|---|---|---|---|
| 3907* | .971 | 1.7 | .1 | 18 | 12 | .003 | .019 | .13 | .033 | .063 |
| 3904 | 1.043 | 1.7 | .2 | 20 | 12 | .003 | .012 | .08 | .023 | .043 |
| 3908* | 1.189 | 1.6 | .6 | 21 | 10 | .003 | .015 | .07 | .037 | .045 |
| 3909* | 1.191 | 1.7 | 1.2 | 20 | 12 | .003 | .012 | .06 | .066 | .035 |
| 3906* | 1.193 | 1.6 | .7 | 23 | 13 | .003 | .015 | .07 | .048 | .043 |
| 3910* | 1.206 | 1.7 | 1.2 | 22 | 12 | .006 | .016 | .07 | .066 | .036 |

* EMPTY HEADS

Table II

AERODYNAMIC DATA LIVE MOTORS

| Rd. | M | $K_D$ | $\delta^2 \times 10^2$ (Rad.) | $\delta_e^2 \times 10^2$ (Rad.) | $K_M$ | $K_N$ | $K_H$ | $K_T$ | $\lambda_1 \times 10^3$ ($ft^{-1}$) | $\lambda_2 \times 10^3$ ($ft^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|---|
| 3899 | 1.290 | -1.665 | .303 | .362 | 2.10 | 1.31 | 6.7 | .01 | 1.71 | 1.22 |
| 3897 | 1.323 | -1.562 | .441 | .589 | 2.09 | 1.13 | 7.5 | -.08 | 1.37 | 1.41 |
| 3896 | 1.346 | -1.499 | .050 | .061 | 2.15 | 1.21 | 12.2 | -.13 | 1.84 | 1.52 |
| 3902 | 1.348 | -1.430 | .135 | .138 | 2.16 | 1.21 | 8.3 | .04 | 2.02 | .90 |
| 3898 | 1.351 | -1.485 | .547 | .754 | 2.10 | 1.20 | 8.5 | -.13 | 1.22 | 1.70 |
| 3895 | 1.352 | -1.507 | .028 | .039 | 2.03 | | 12.4 | -.15 | 1.78 | 1.38 |
| 3900 | 1.357 | -1.415 | .231 | .252 | 2.15 | 1.14 | 8.6 | -.04 | 1.72 | 1.15 |
| 3901 | 1.385 | -1.371 | .187 | .187 | 2.18 | 1.16 | 11.6 | -.12 | 1.79 | 1.48 |

| Rd. | M | s | $\bar{s}$ | N | $N_T$ | $\epsilon y$ (ft) | $\epsilon s$ (ft) | $s_L$ (ft) | $K_{10}$ (Rad.) | $K_{20}$ (Rad.) |
|---|---|---|---|---|---|---|---|---|---|---|
| 3899 | 1.290 | 1.6 | .9 | 18 | 10 | .002 | .020 | .18 | .034 | .037 |
| 3897 | 1.323 | 1.7 | 1.0 | 19 | 13 | .002 | .025 | .21 | .045 | .042 |
| 3896 | 1.346 | 1.7 | 1.0 | 19 | 12 | .002 | .012 | .07 | .014 | .015 |
| 3902 | 1.348 | 1.6 | .8 | 21 | 11 | .002 | .018 | .12 | .019 | .028 |
| 3898 | 1.351 | 1.7 | 1.1 | 21 | 10 | .002 | .025 | .20 | .053 | .040 |
| 3895 | 1.352 | 1.7 | .9 | 16 | 11 | .003 | | .06 | .010 | .015 |
| 3900 | 1.357 | 1.6 | .9 | 23 | 13 | .003 | .012 | .14 | .027 | .035 |
| 3901 | 1.385 | 1.6 | 1.0 | 18 | 9 | .003 | .012 | .11 | .024 | .028 |

## APPENDIX B

## GRAPHS AND PHOTOGRAPHS


FIGURE 1 T231 ROCKET

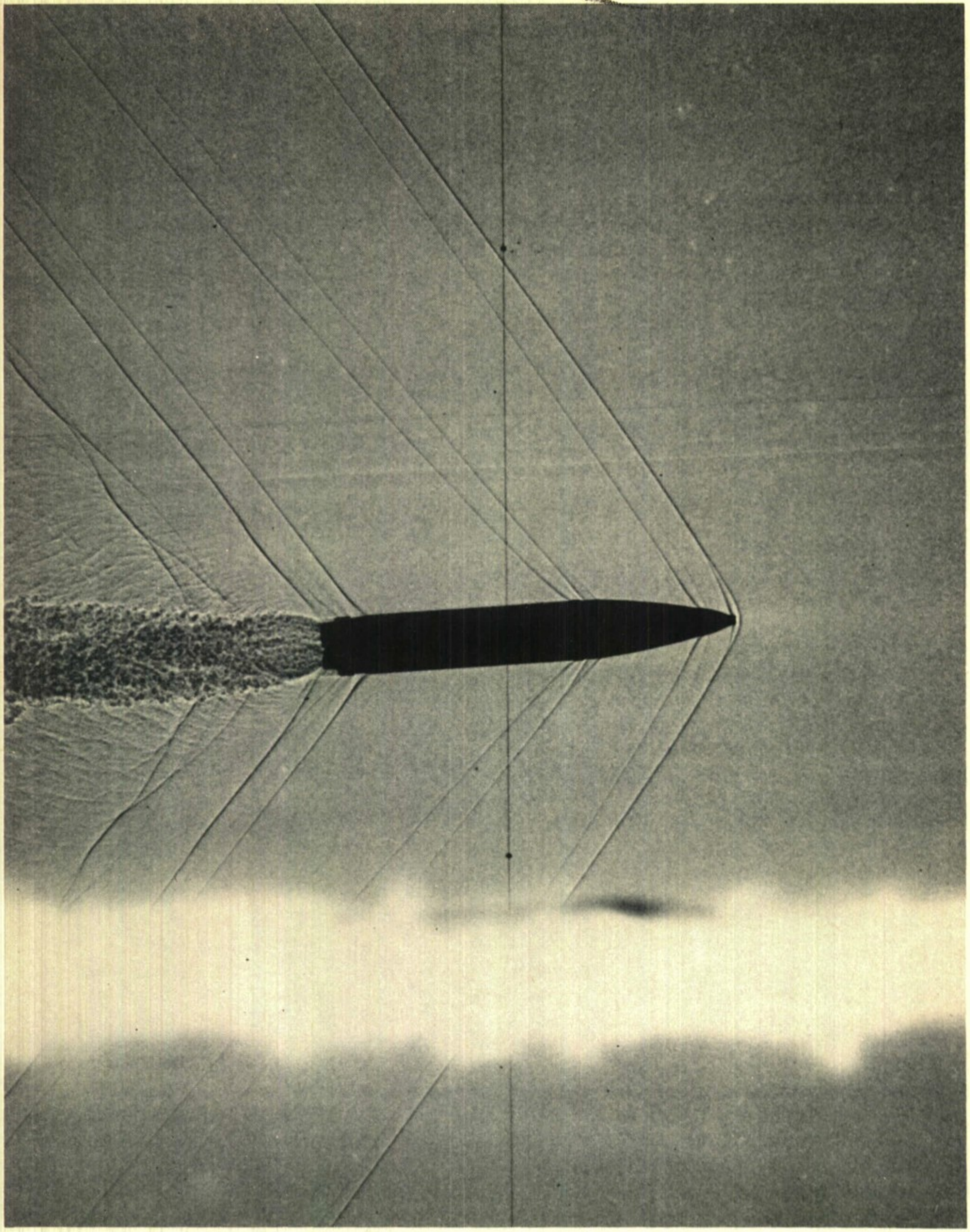


FIGURE 2 ROCKET IN FREE FLIGHT (VELOCITY 1565 fps)

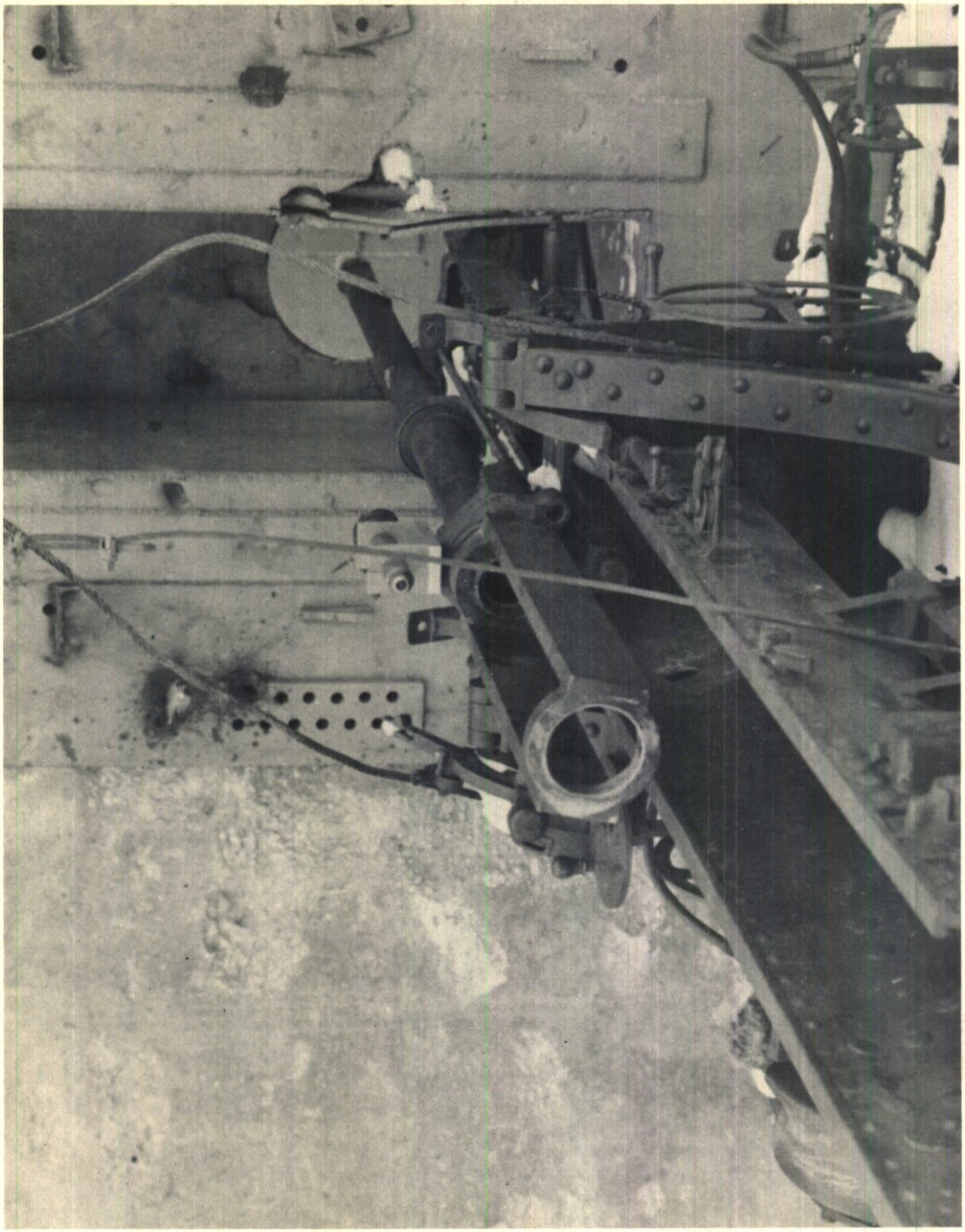


FIGURE 3 ROCKET LAUNCHER

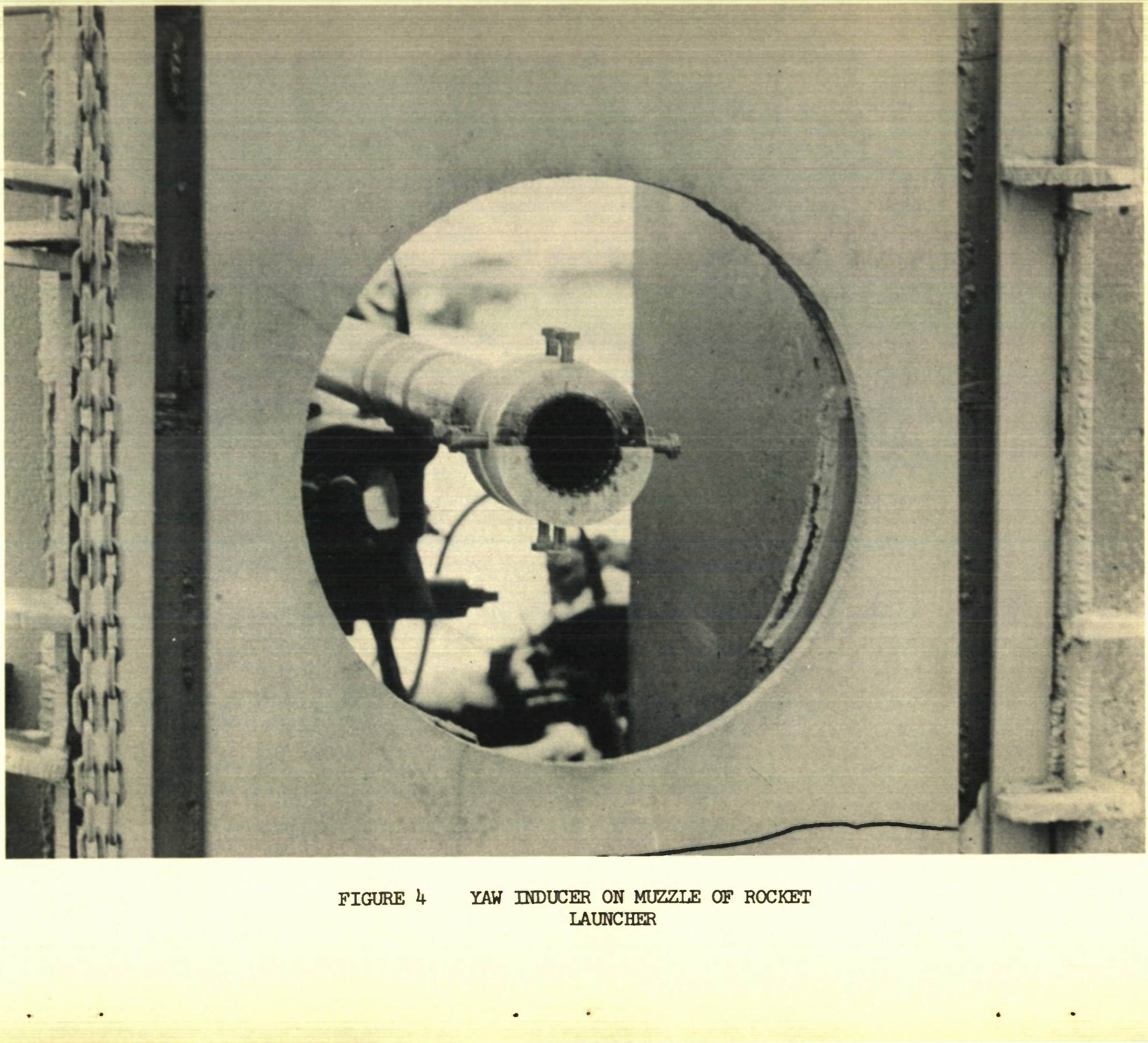
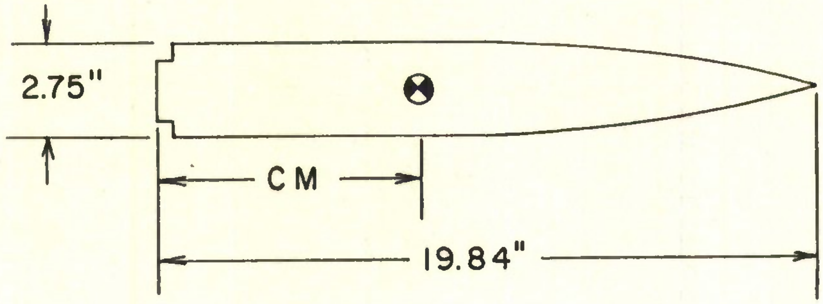


FIGURE 4 YAW INDUCER ON MUZZLE OF ROCKET LAUNCHER

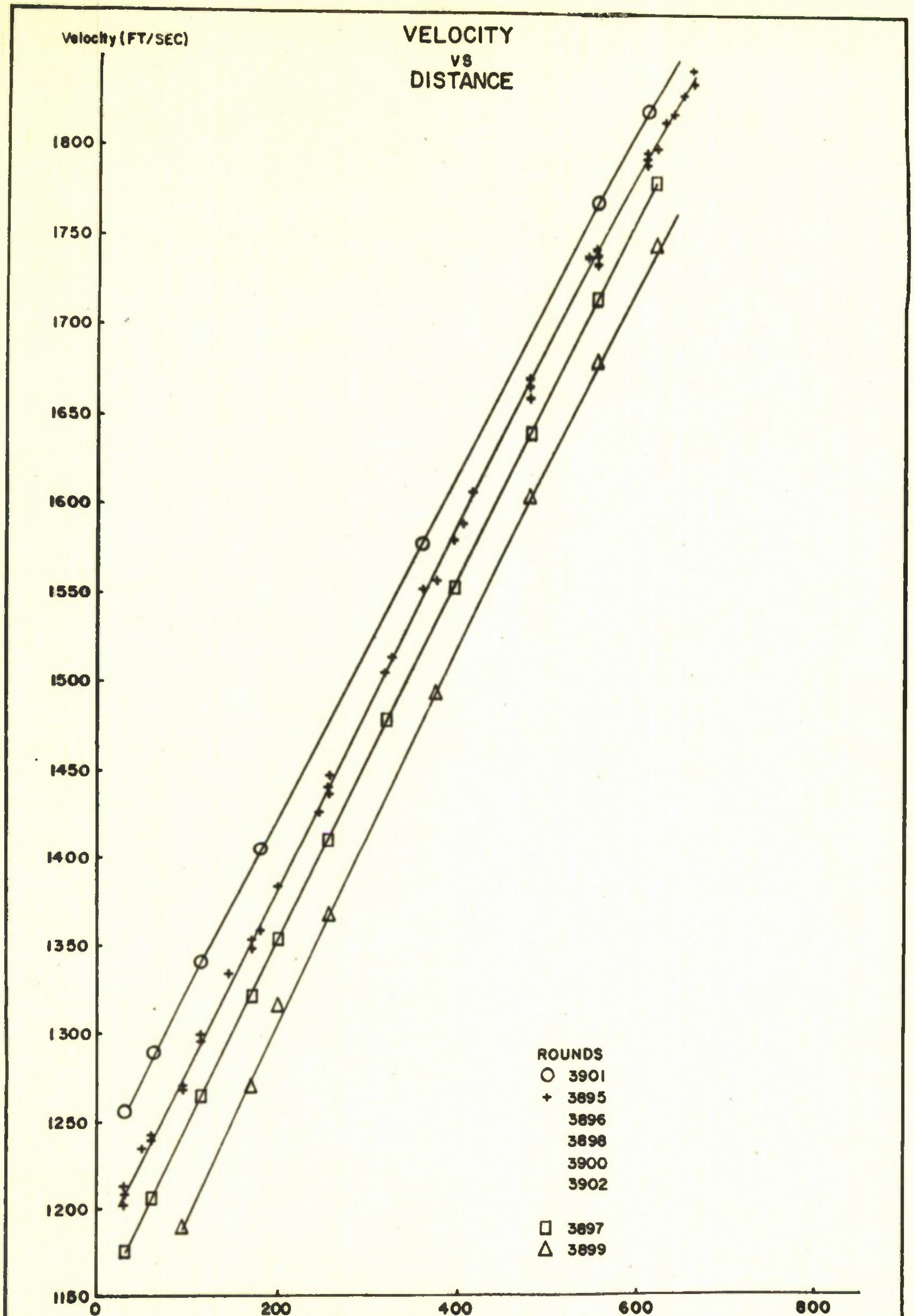
PHYSICAL PROPERTIES




| | LIVE MOTOR | LIVE MOTOR AT 350 FT. FROM MUZZLE* | BURNT MOTOR | BURNT MOTOR EMPTY HEAD |
|---|---|---|---|---|
| A - $lb\text{-}in^2$ | 10.9 | 10.1 | 7.9 | 7.4 |
| B - $lb\text{-}in^2$ | 249.0 | 235.6 | 200.9 | 177.3 |
| cm - in | 9.24 | 9.53 | 10.32 | 9.61 |
| m - lb | 9.30 | 8.53 | 6.43 | 5.54 |

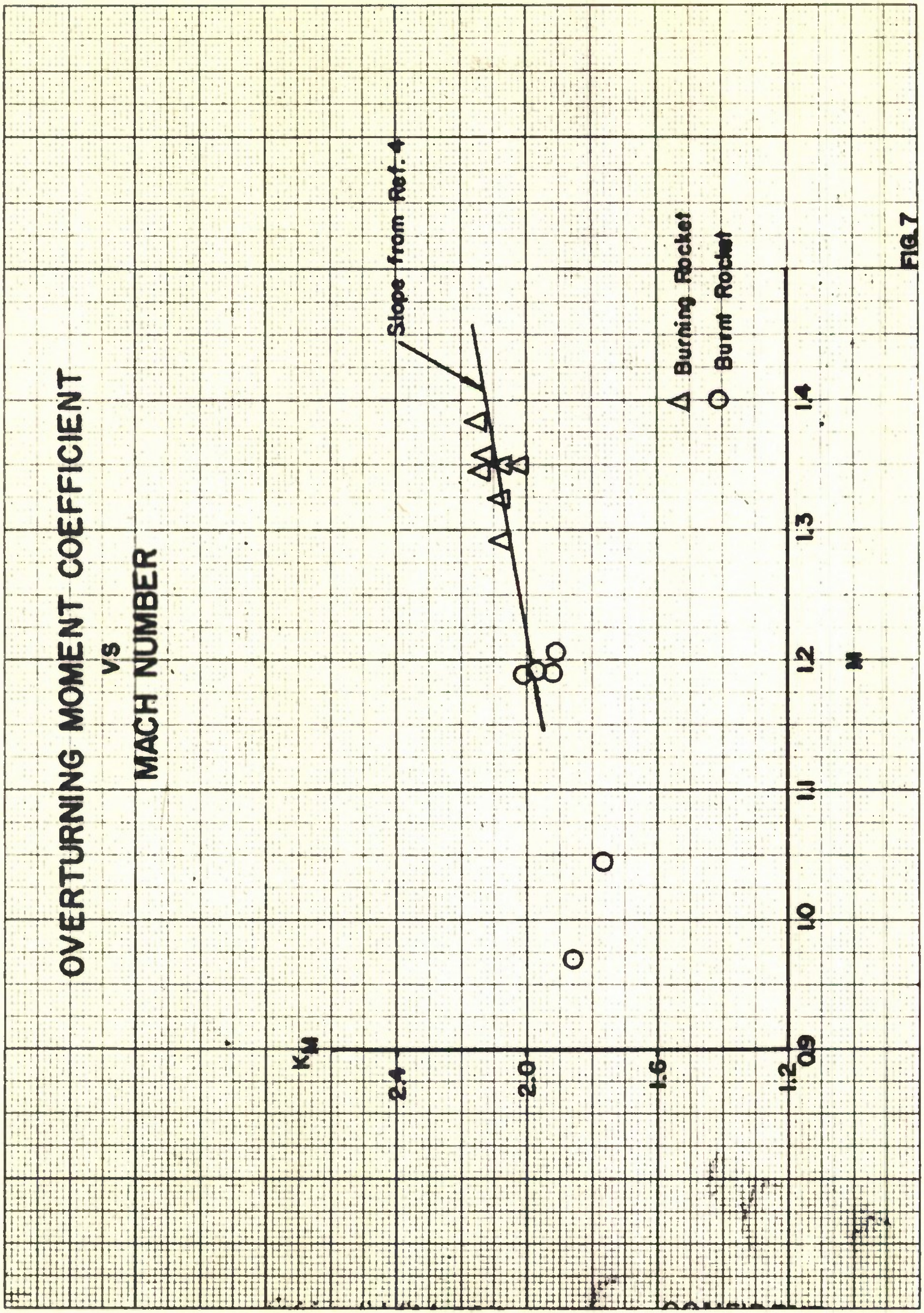
* Midpoint of observations

Figure 5



VELOCITY
VS
DISTANCE
Velocity (FT/SEC)
1800
1750
1700
1650
1600
1550
1500
1450
1400
1350
1300
1250
1200
1150
0
200
400
600
800
Distance (FT)
ROUNDS
3901
3895
3896
3898
3900
3902
3897
3899


FIG. 6




OVERTURNING MOMENT COEFFICIENT vs MACH NUMBER

FIG. 7

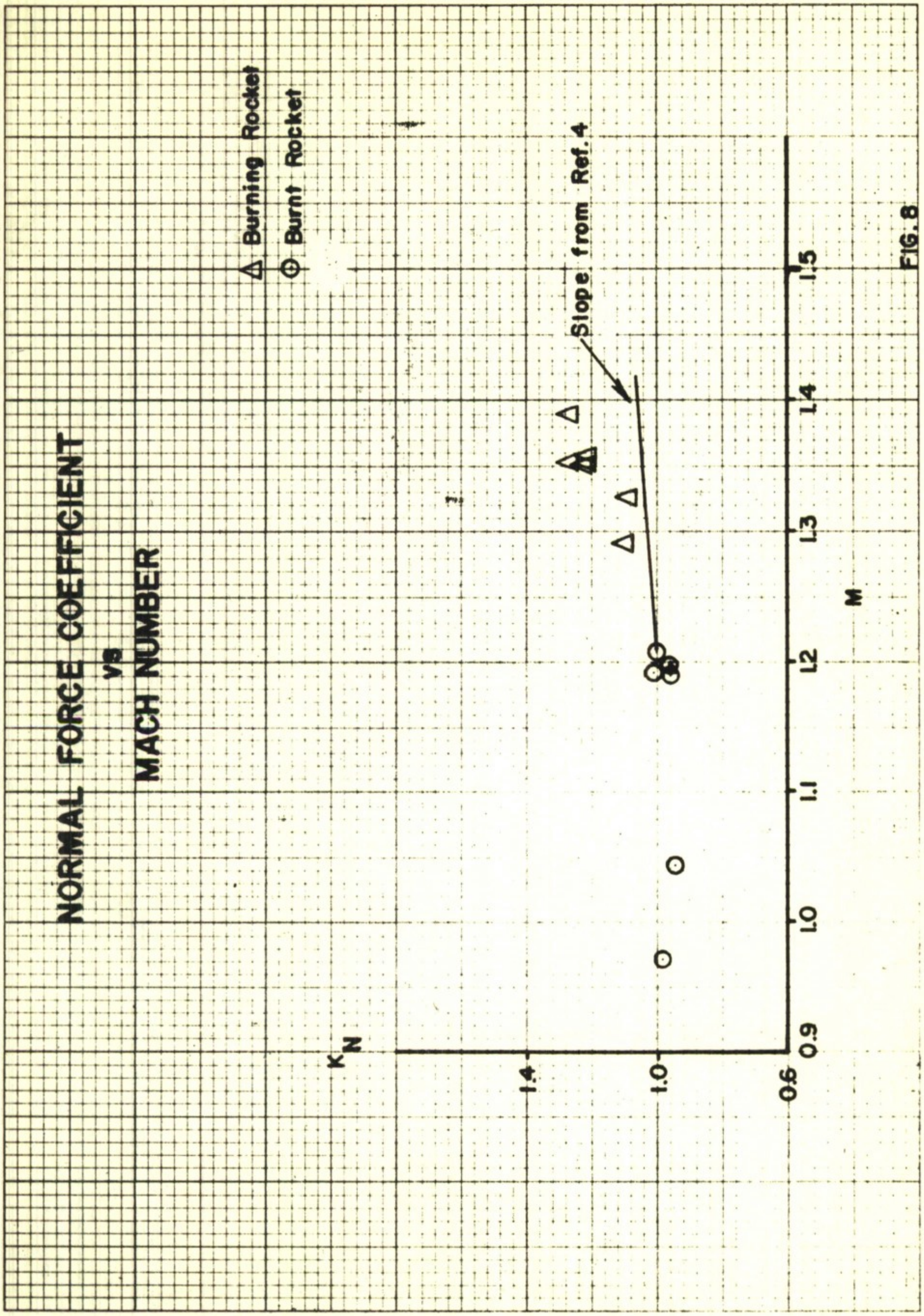

NORMAL FORCE COEFFICIENT
vs
MACH NUMBER
△ Burning Rocket
⊙ Burnt Rocket
Slope from Ref. 4
$K_N$
1.4
1.0
0.6
0.9
1.0
1.1
1.2
1.3
1.4
1.5
M

FIG. 8

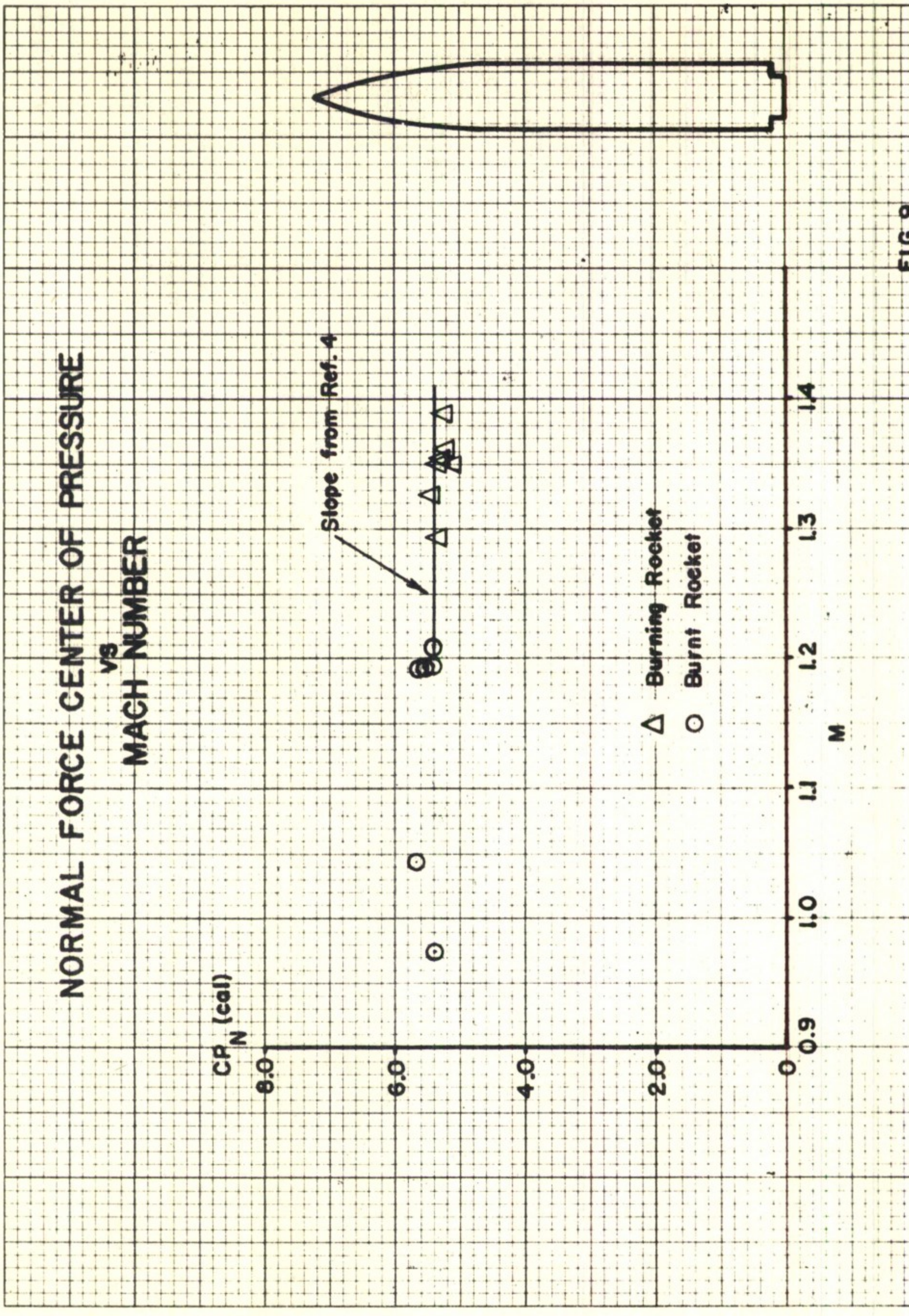

NORMAL FORCE CENTER OF PRESSURE
VS
MACH NUMBER
$CP_N$ (cal)
8.0
6.0
4.0
2.0
0
0.9
1.0
1.1
1.2
1.3
1.4
M
Slope from Ref. 4
△ Burning Rocket
⊙ Burnt Rocket

FIG. 9

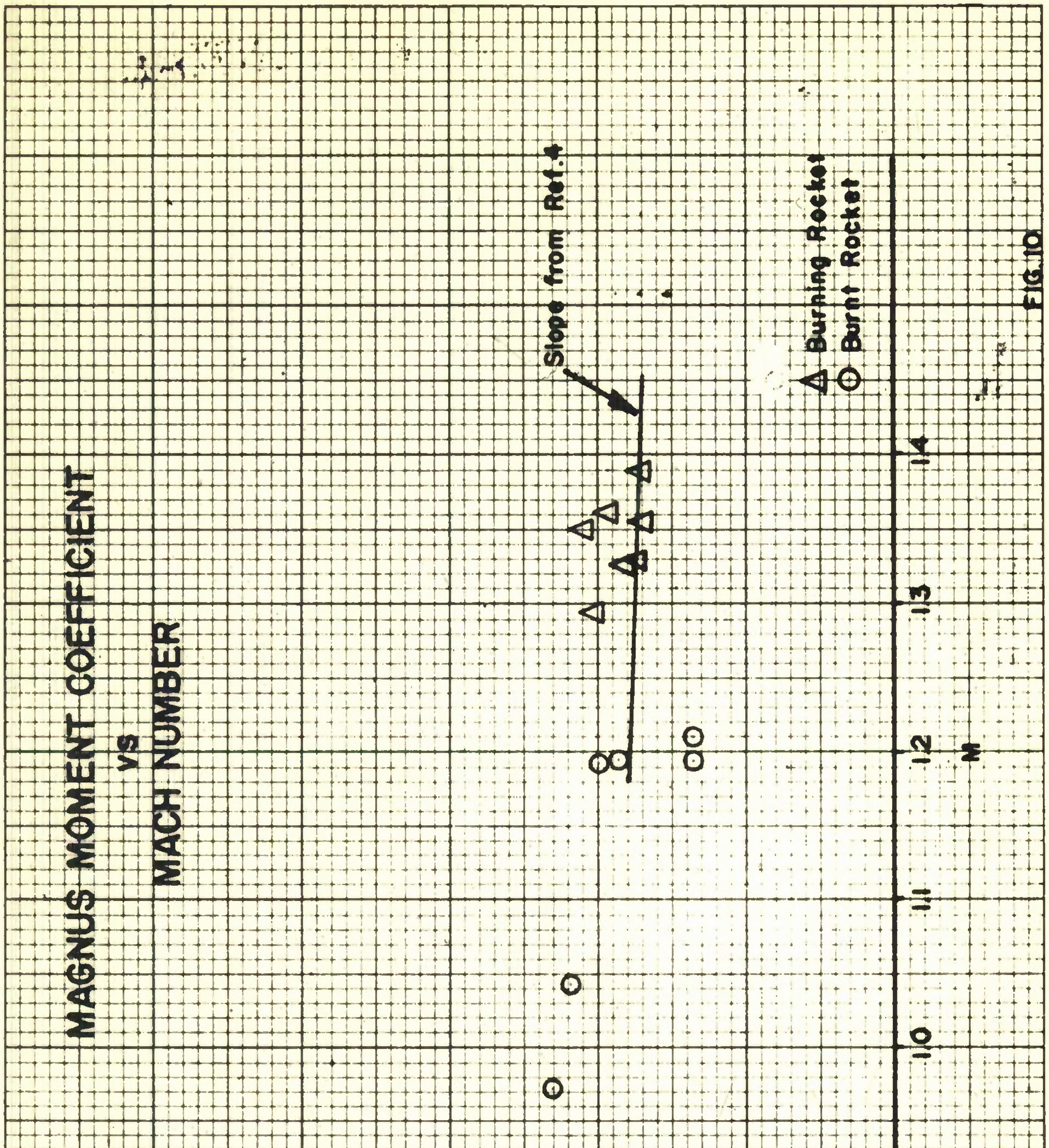

MAGNUS MOMENT COEFFICIENT
vs
MACH NUMBER
Slope from Ref.4
△ Burning Rocket
⊙ Burnt Rocket
$K_T$
.2
0
-.2
-.4
0.9
1.0
1.1
1.2
1.3
1.4
M

FIG. 10

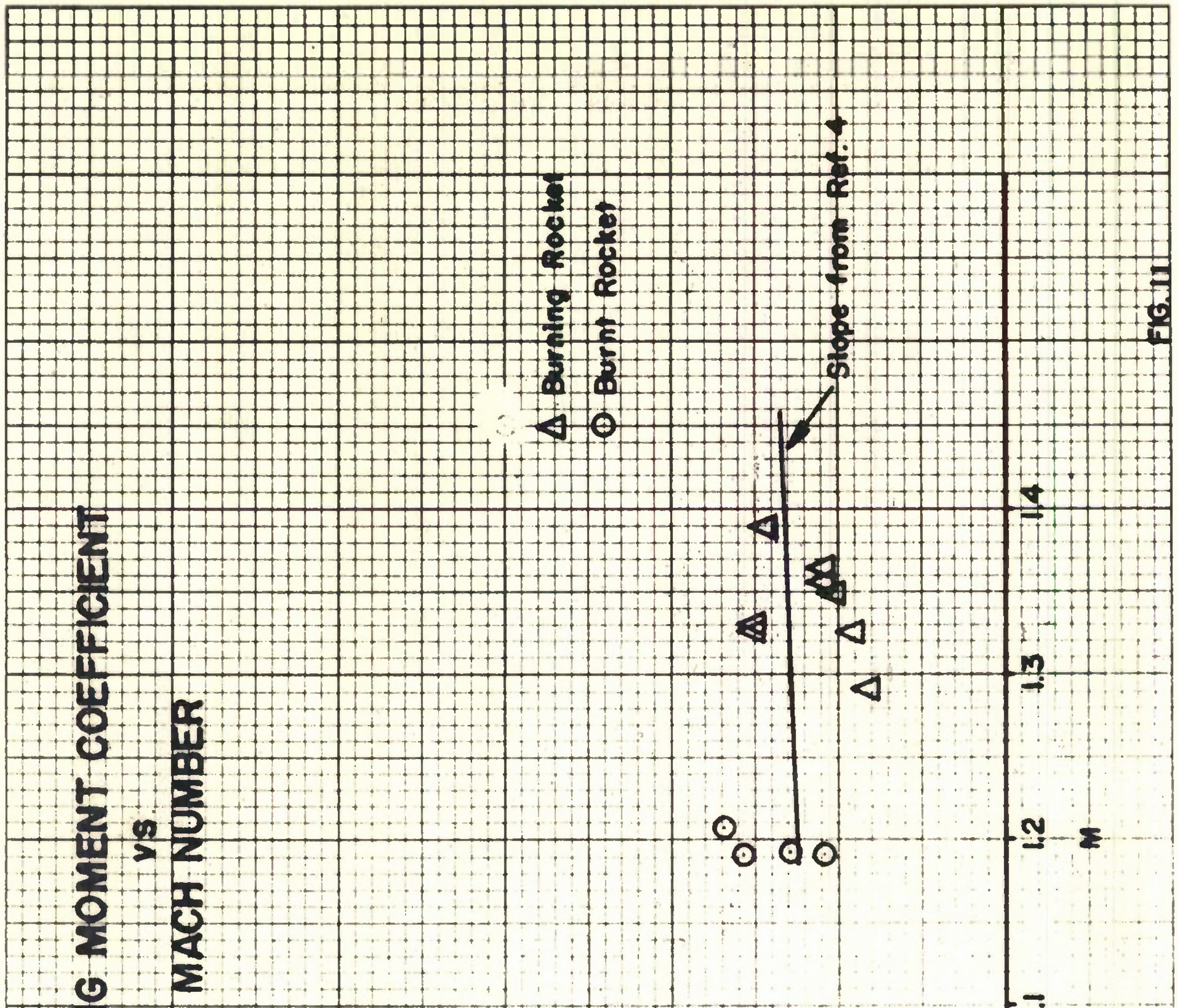

DAMPING MOMENT COEFFICIENT
VS
MACH NUMBER
Δ Burning Rocket
⊙ Burnt Rocket
Slope from Ref. 4
$K_H - K_{MA}$
16
8
0
0.9
1.0
1.1
1.2
1.3
1.4
M

FIG. 11

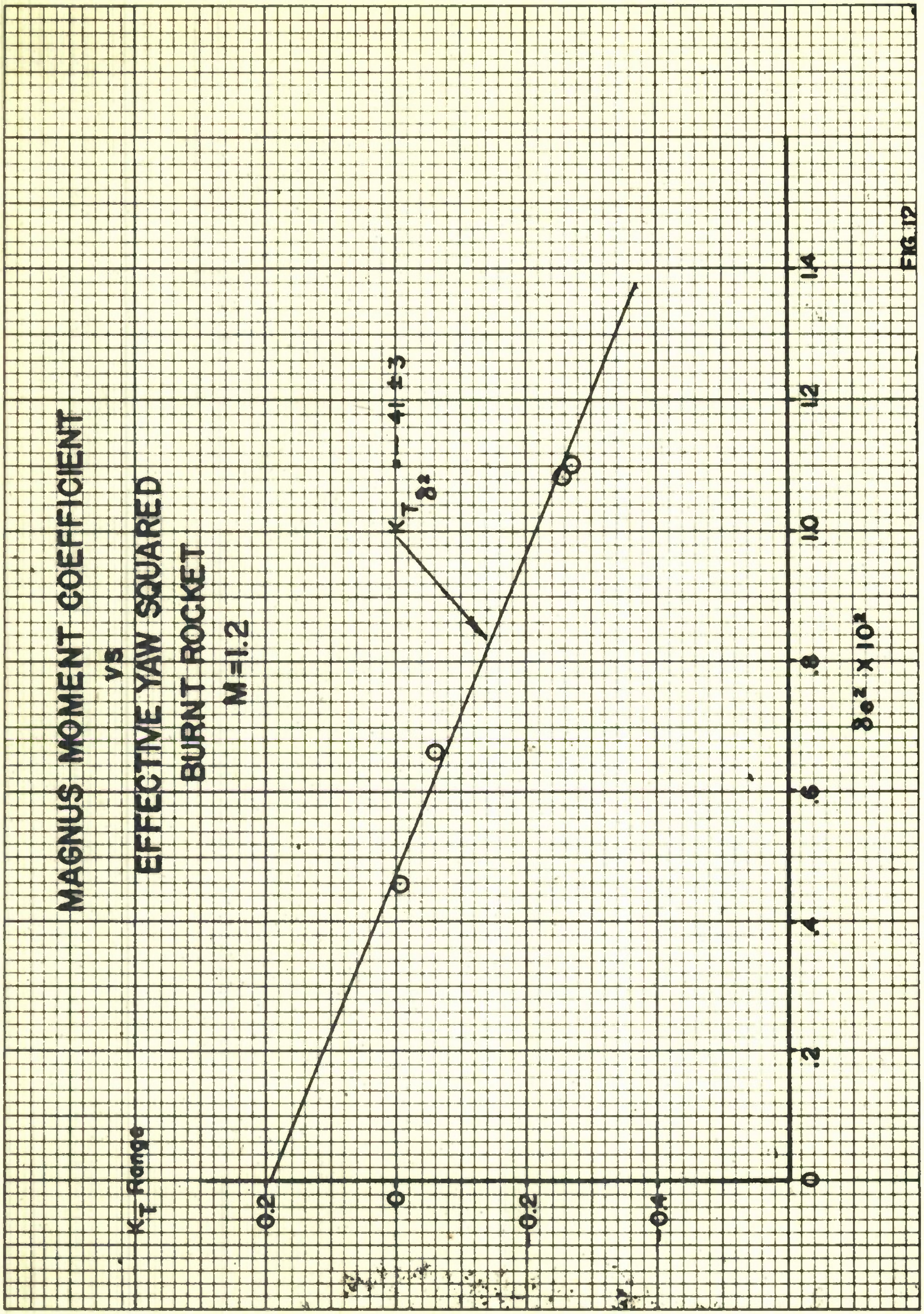

MAGNUS MOMENT COEFFICIENT
VS
EFFECTIVE YAW SQUARED
BURNT ROCKET
M=1.2
K_T Range
$K_{T_{\delta^2}} = -41 \pm 3$
.2
0
.2
.4
0
.2
.4
.6
.8
1.0
1.2
1.4
$\delta_e^2 \times 10^2$

FIG. 12

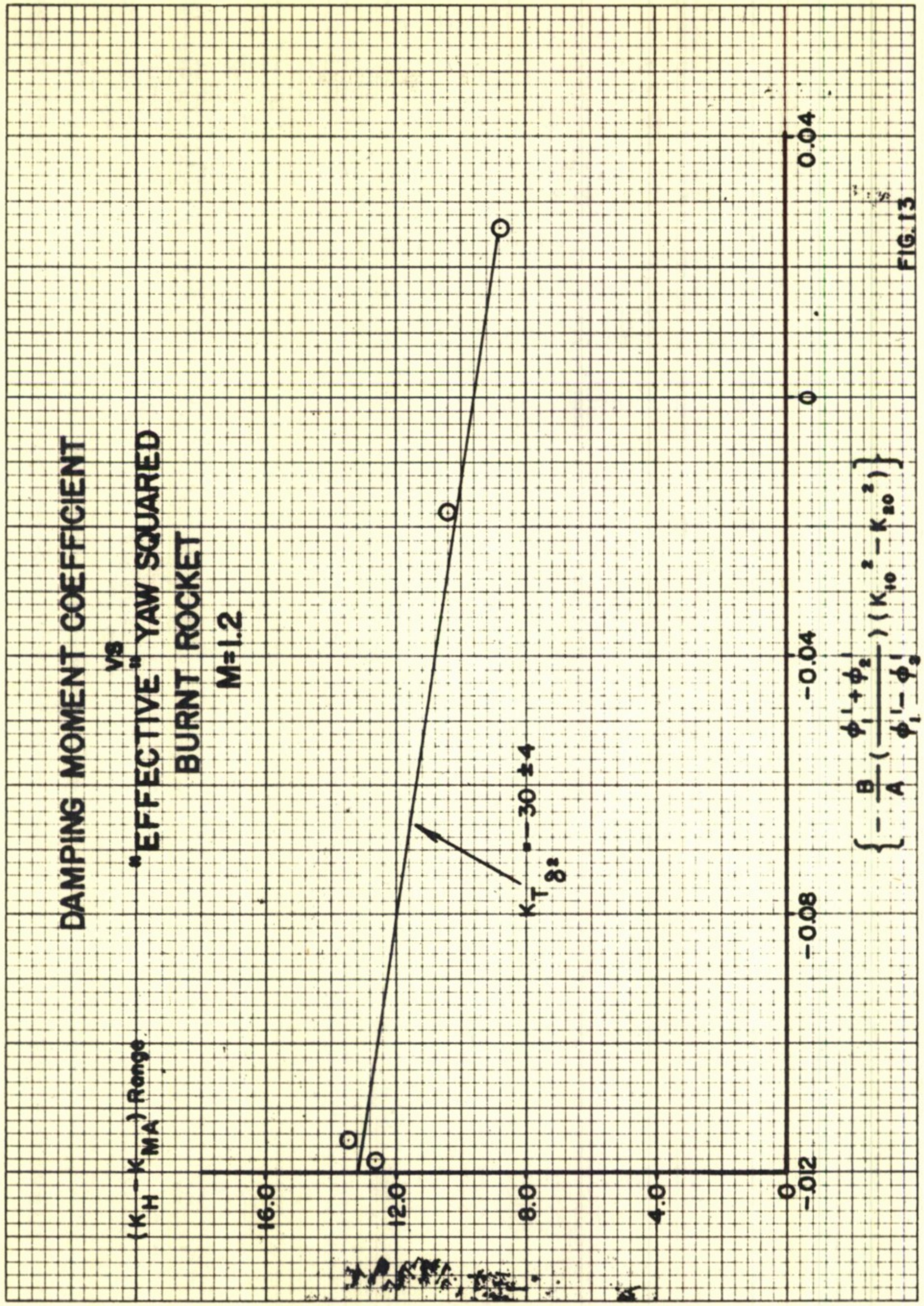

DAMPING MOMENT COEFFICIENT
VS
"EFFECTIVE" YAW SQUARED
BURNT ROCKET
M=1.2
$(K_H - K_{MA})$ Range
$K_{T_{\delta^2}} = -30 \pm 4$
16.0
12.0
8.0
4.0
0
-0.12
-0.08
-0.04
0
0.04
$\left\{ -\frac{B}{A}\left(\frac{\phi_1' + \phi_2'}{\phi_1' - \phi_2'}\right)(K_{10}^2 - K_{20}^2) \right\}$

FIG. 13

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| 1 | Commanding General<br>Redstone Arsenal<br>Huntsville, Alabama<br>Attn: Technical Library |
| 3 | Commanding Officer<br>Picatinny Arsenal<br>Dover, New Jersey<br>Attn: Samuel Feltman<br>Ammunition Labs. |
| 1 | Commanding General<br>Frankford Arsenal<br>Philadelphia 37, Penna.<br>Attn: Reports Group |
| 1 | Commanding Officer<br>Chemical Corps Chemical and Radiological Lab.<br>Army Chemical Center, Maryland |
| 1 | Applied Physics Laboratory<br>8621 Georgia Avenue<br>Silver Spring, Maryland<br>Attn: Mr. George L. Seielstad |
| 1 | Cornell Aeronautical Lab., Inc.<br>4455 Genesee Street<br>Buffalo, New York<br>Attn: Miss Elma T. Evans<br>Librarian<br>THRU: Bureau of Aeronautics Representative<br>4455 Genesee Street<br>Buffalo 21, New York<br>Attn: Commander Bolles |
| 1 | Wright Aeronautical Division<br>Curtiss-Wright Corporation<br>Wood-Ridge, New Jersey<br>Attn: Sales Dept. (Government)<br>THRU: Air Force Plant Representative<br>Wright Aeronautical Division<br>Wood-Ridge, New Jersey |